Transport of Aerosol Pollution into Michigan

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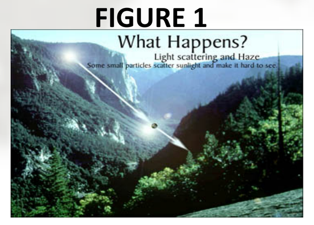
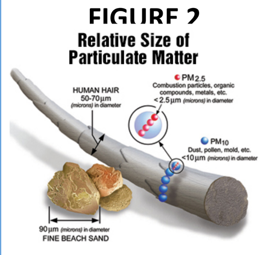
Introduction

FIGURE 1



Aerosol particles, or particulate matter, are a major contributor to air pollution in the industrialized corners of our world. 2014 Meta analysis report shows that long term exposure to particulate matter is linked to coronary events[1]. A recent European study of 100,000 patients followed for 11.5 years with annual exposure to fine particulate matter ($PM_{2.5}$) of just 5mg/m³ resulted in 13% increase risk of heart attacks[1]. The current study explores the impact of aerosols on Michigan air quality using a mixture of 9 ground truth sites and satellite data. This study uses two different measures of ground Aerosol particulate pollution- Particulate Matter 2.5 and Aerosol Optical Depth (AOD). The $PM_{2.5}$ data is obtained from ground based data stations while the AOD data is obtained from two very different sources; the first is ground based looking up through the atmosphere while the second is space based looking down through the atmosphere. AOD data collection, by its nature, is restricted to days with clear skies. As a result, many of the data plots contain only sporadic AOD data.

FIGURE 2



Aerosol optical depth (AOD), Figure 1, is a measure of the extinction of a solar beam by dust and haze. In other words, particles smaller than 2.5 micrometers in diameter suspended in the atmosphere (dust, smoke, pollution) can block sunlight by absorbing it or by scattering the light beam in random directions. AOD tells us how much direct sunlight is prevented from reaching the ground by these aerosol particles. It is a dimensionless number that is related to the amount of aerosol in the vertical column of atmosphere over the observation location. A value of 0.01 corresponds to an extremely clean atmosphere, and a value of 0.4 corresponds to a very hazy condition. An average aerosol optical depth for the U.S. is between 0.1 to 0.15. $PM_{2.5}$ is a subset of airborne particulate matter that has a diameter of 2.5 micrometers or less (Figure 2). $PM_{2.5}$ is mostly composed of ammonium nitrate, ammonium sulfate, and organic carbon[2]. These particles are emitted from sources like forest fires, power plants emissions, and internal combustion engines[2]. Studies have found a link between $PM_{2.5}$ and Aerosol Optical Depth (AOD)[3,4,5,6]. Figure 3 presents the particulate source of $PM_{2.5}$ aerosols in the state of Michigan based upon 2011 studies. Figure 4 details the statewide distribution of $PM_{2.5}$ based upon 2011 data. The national air quality limit for $PM_{2.5}$ is 35 μg/m³.

FIGURE 3: $PM_{2.5}$ Emissions by Source Sector

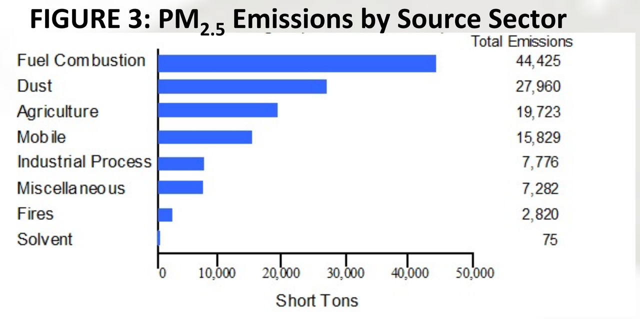
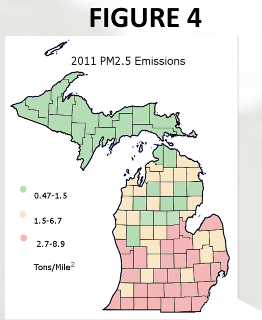
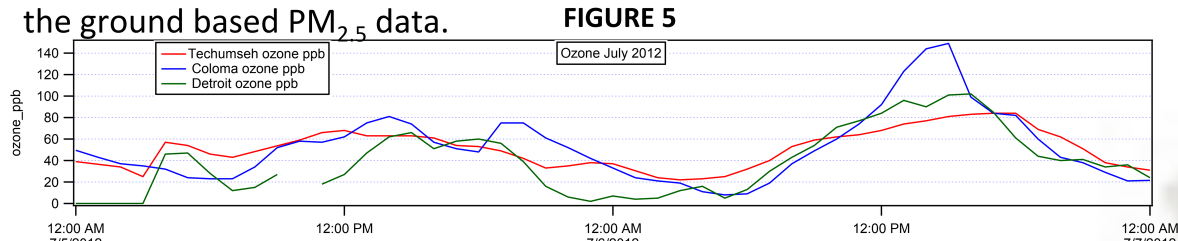


FIGURE 4



NASA utilizes two Earth observing satellites which are most useful for this study- Terra and Aqua. These two satellites have been collecting a vast database, referred to as MODIS (Moderate Resolution Imaging Spectro Radiometer. For the current study, the frequency of most interest is 550 nm. The data can be obtained as both a tabulation of values and as colored regions superimposed upon regional maps. The data is only obtainable on days with clear skies, thus there are gaps in the record when compared with the ground based $PM_{2.5}$ data.

FIGURE 5



Last year's LEARN research included a Michigan ozone study that showed that the west side of Michigan had unusually high ozone events. Figure 5 illustrates an event that took place in Coloma, on the west side of the state, compared to Techumseh in the middle of the state and Detroit on the east side. Despite being a small city Coloma's ozone was consistently higher than large cities like Detroit. That study supported the hypothesis that dirty air masses originate in the industrial cities on the western shore of Lake Michigan and move across the lake to the western edge of Michigan.

Sensor Locations

Michigan

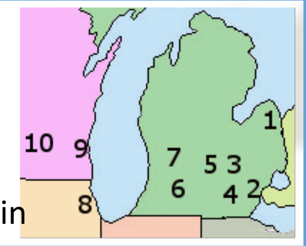
1. Port Huron
2. Detroit
3. Flint
4. Tecumseh
5. Lansing
6. Kalamazoo
7. Grand Rapids

Wisconsin

8. Chicago
9. Milwaukee

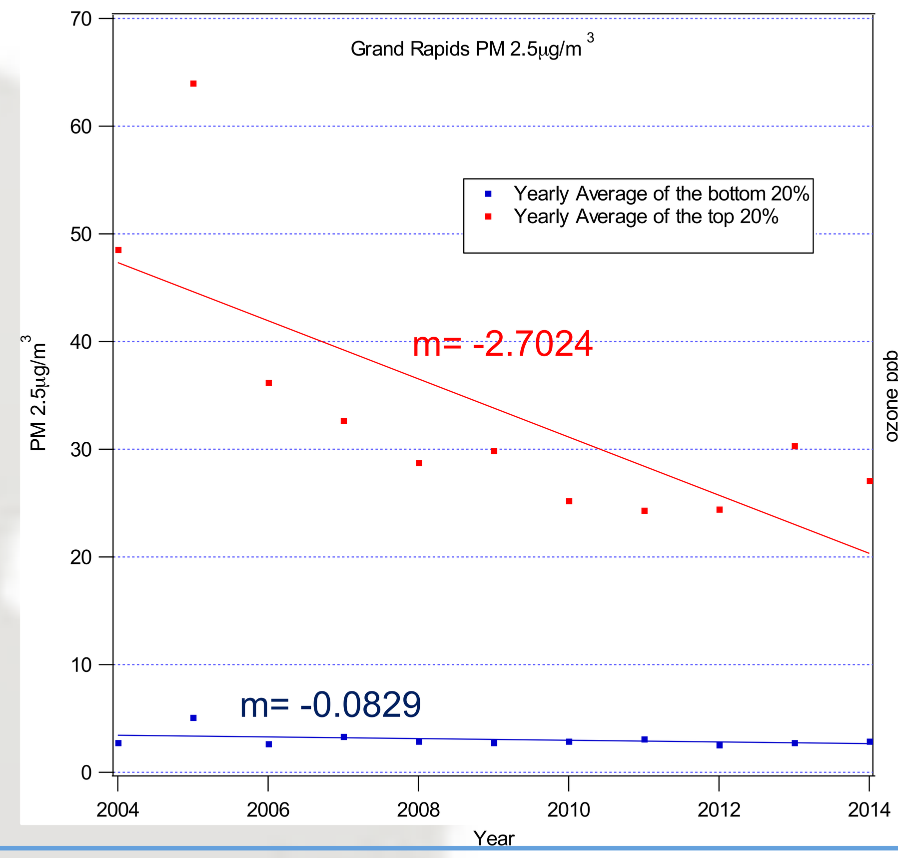
Illinois

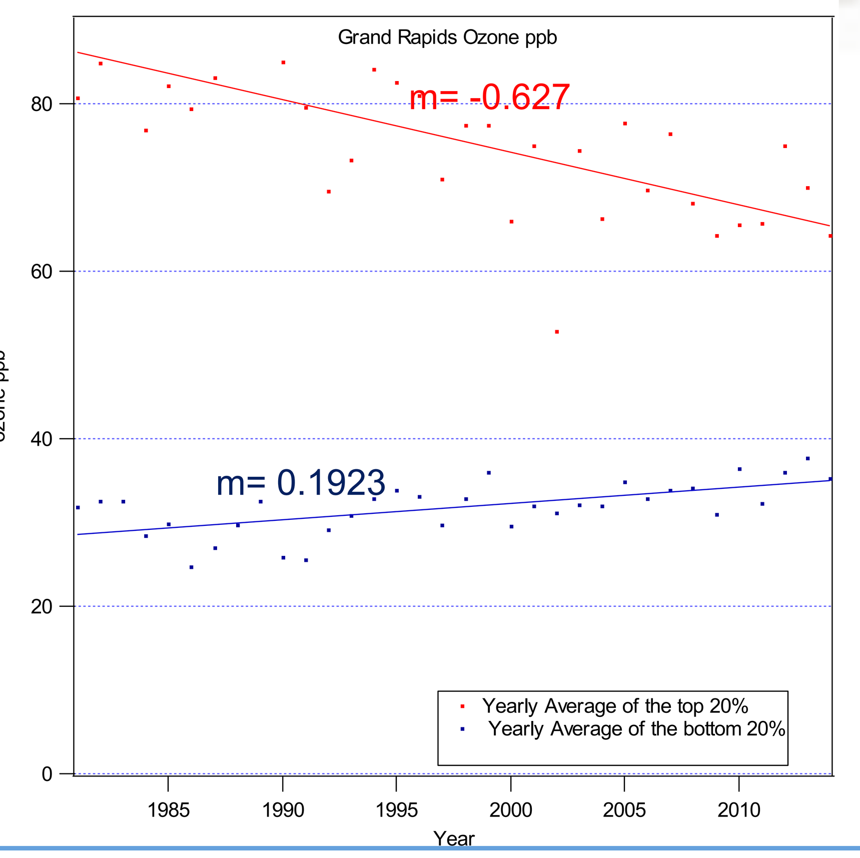
10. University of Wisconsin



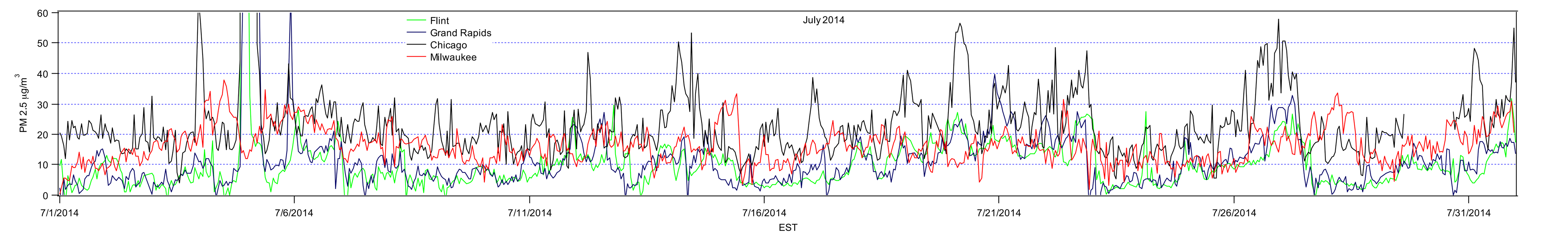
Grand Rapids Long Term

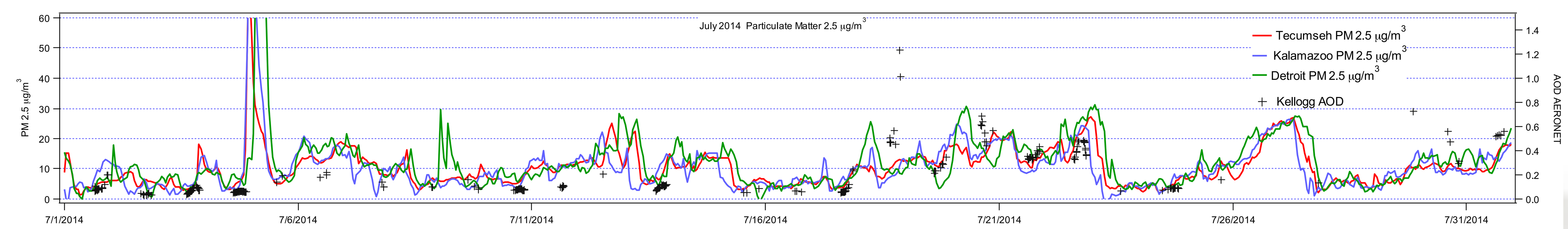
The graphs to the right present averaged data for $PM_{2.5}$ and Ozone respectively of both the top and bottom 20% readings versus calendar years. It can be seen that the trends for both the top 20% curves show a steady decline, which indicates an improvement in air quality. The $PM_{2.5}$ bottom 20% curve shows a small decrease while the ozone curve shows a modest increase. The maximum values are getting cleaner with time.

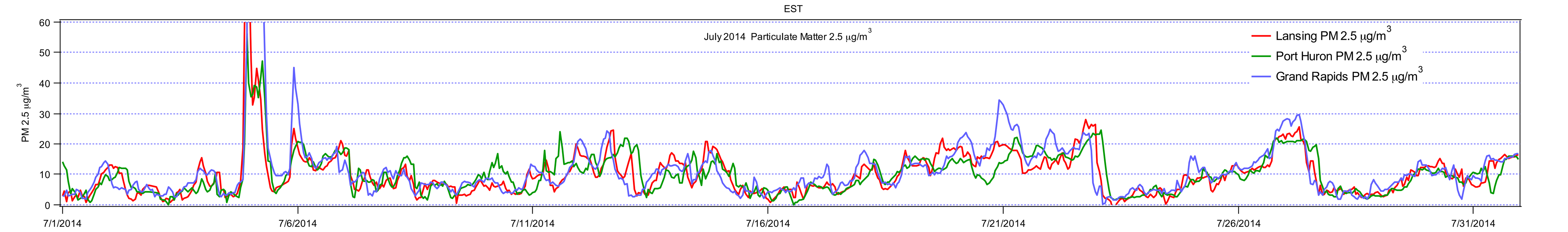


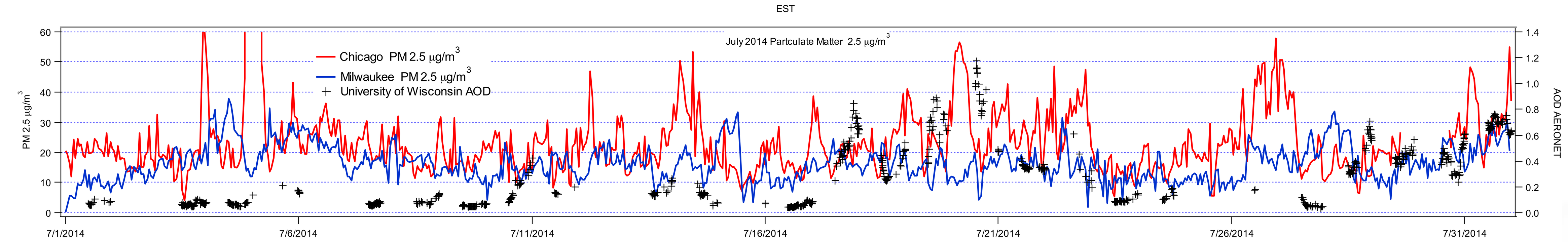


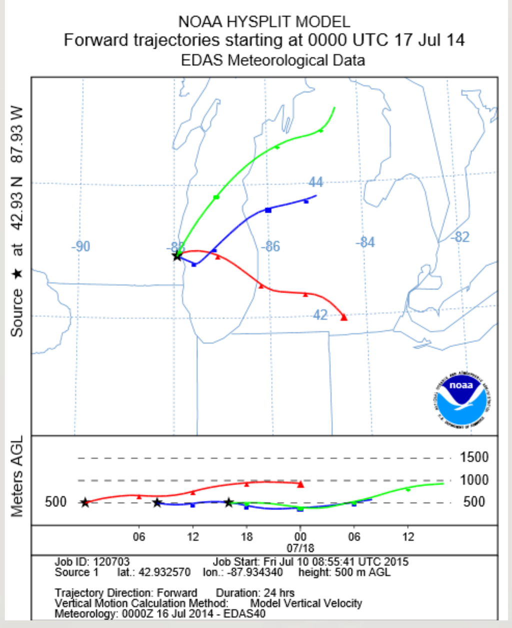
July 2014



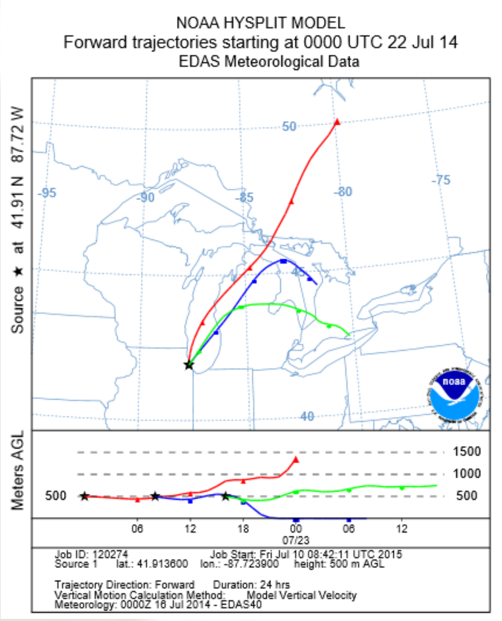








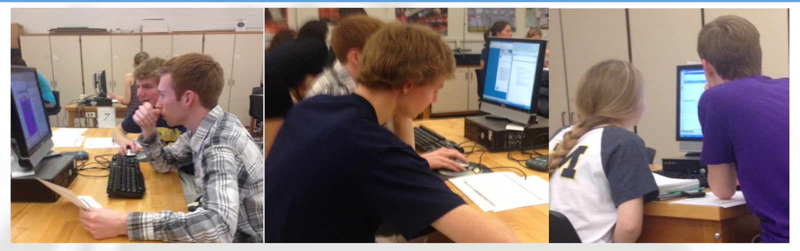
EDAS Forward Trajectory
July 17,2014



EDAS Forward Trajectory
July 22,2014

The top plot above presents $PM_{2.5}$ data for July of 2014, for the cities of Flint, Grand Rapids, Chicago and Milwaukee. The second plot presents $PM_{2.5}$ data for the month of July for the cities of Tecumseh, Kalamazoo, Detroit and AOD data for Kellogg. The third plot presents $PM_{2.5}$ for the cities of Lansing, Port Huron and Grand Rapids. The AOD data, which uses the scale to the right of the plot, generally follows the $PM_{2.5}$ data pattern. All six of these $PM_{2.5}$ locations experience a dynamic spike on July 4th, easily surpassing the 24 hour average air quality standard of 35 μg/m³ with readings in excess of 100 μg/m³ . All of the sites experience a volatile spike on the 13th followed by a quick drop to low levels that night. This sequence repeats with less change on the 15th, building to a larger peak-trough event on the 23rd, with the sequence repeated on the 27th. The ramp event between the 16th and 23rd is especially noteworthy as it contains daily cycles in readings as the daily averages climb in value. The forward trajectories to the left show that the air masses are traveling from Chicago and Milwaukee into western Michigan. The lower plot presents $PM_{2.5}$ data for the cities of Chicago, Milwaukee AOD data from the University of Wisconsin at Madison.

Student Involvement



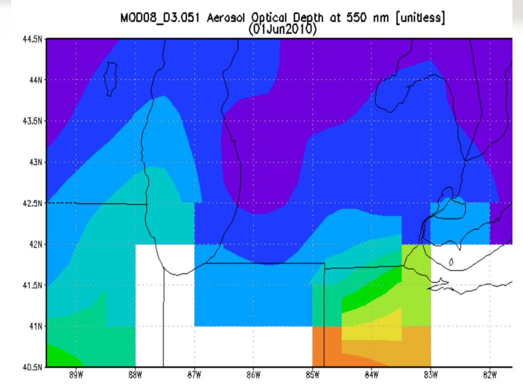
Small groups of AP Physics C students (N=65) were provided time series graphs of $PM_{2.5}$ and AOD for one of the ground stations in Michigan. They investigated the correlation between the two means of measuring aerosols. They also looked through the data for regions of interest, either splits between the curves or significant rises or falls. After identifying an interesting event, the students investigated the relevant satellite data assessing its correlation with the ground source and performed trajectories, looking for correlation with a source on the west coast of Lake Michigan (Figure 6).

Examples of Student Work

Examining satellite data gave the students an overall picture of AOD distribution over the state of Michigan, figure 6. The time series graph data made it possible for students to see the daily fluctuations of $PM_{2.5}$ and AOD as well as assess the correlation between these two different techniques of measuring aerosol levels. Figure 7 illustrates the differences between the data obtained from the different measurement techniques yet also illustrates that the general curves form a consistent representation of the daily trends.

Figure 6: Aerosol Optical Depth at 550nm

TERRA



AQUA

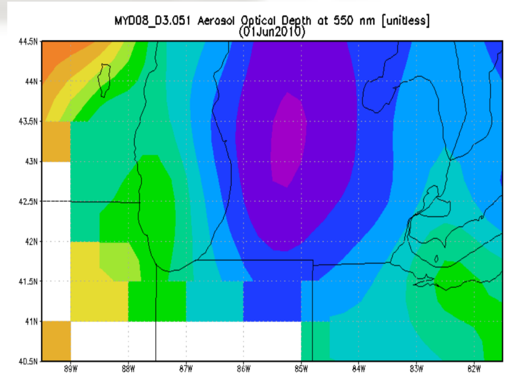
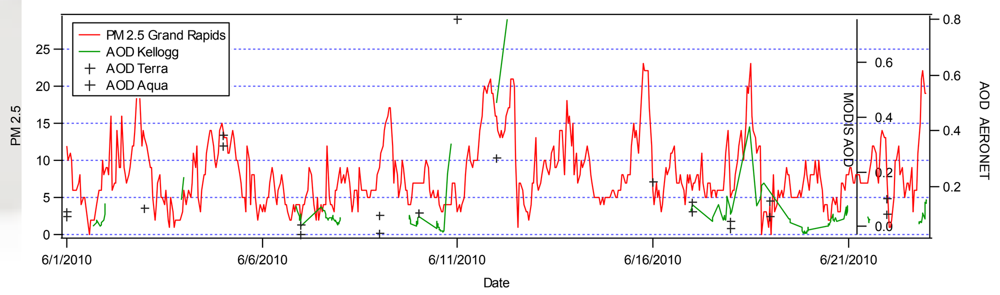


Figure 7: PM 2.5 and AOD Daily Fluctuations



Conclusions

Unlike the ozone levels observed in last year's study, the aerosol levels fall off having traveled across Lake Michigan. Michigan cities experience similar aerosol levels while Chicago experiences the most. Milwaukee's aerosol levels varies the most, with its peaks nearly matching the results from Chicago and while its nominal levels are closer to that of the Michigan cities.

The yearly average graph provides clear evidence that the aerosol levels are being reduced, with even the peak values being below the standard $PM_{2.5}$ allowable of 35 μg/m³. All but two of the sites registered aerosol spikes over 3 times the healthy level on July 4th.

References

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